

RTCA Special Committee 186, Working Group 5

ADS-B UAT MOPS

Meeting #12

**Draft 2 of Section 3 for
Review in Washington**

Presented by Tom Mosher

SUMMARY
This is Draft 2 of the proposed Section 3 of the UAT MOPS, presented by Tom Mosher for review in Washington.

1 PURPOSE AND SCOPE

2 Equipment Performance Requirements and Test Procedures

3 Equipment Performance Characteristics

This section states the minimum acceptable level of performance for the equipment when installed in the aircraft. Installed performance requirements are the same as contained in §2.2, which are verified through bench and environmental testing. Some system attributes and performance aspects may be affected by the physical installation (e.g. antenna patterns can affect system transmit and receive performance). System integrators might have several options when connecting to aircraft sensors or data sources. Some sources might lack the necessary range, resolution or accuracy to support the desired applications. This section identifies system attributes which installation techniques and choices might affect, beyond the equipment manufacturer's ability to compensate.

3.1 Equipment Installation

Equipment selection and installation characteristics must be appropriate for the airframe and location in which it is installed.

3.1.1 Installed Equipment Considerations

A complete ADS-B system consists of five (5) functional elements:

1. Data sources for aircraft position, velocity, flight plan, status, etc.
2. ADS-B Transmitter
3. ADS-B Receiver
4. Report Assembly
5. Applications

Each of these elements must meet the minimum requirements for an application in order for operational approval to be granted for that application. Additional guidance for determining requirements is contained in §3.1.1.1 through §3.1.1.5.

3.1.1.1 Data Sources

Data sources necessary to support an application shall meet the requirements of the operational environment. (e.g. The source of ADS-B navigation data must be approved for IFR navigation if the ADS-B application is to be approved for IFR operations.) and shall meet the accuracy, range, and resolution requirements of the appropriate ADS-B equipage category.

3.1.1.2 ADS-B Transmitter

Transmitter RF power categories are defined in §2.1.12. All configurations of UAT ADS-B transmitters may be used for VFR and IFR applications. Some applications may require support for other specific message content. The transmitter antenna feed line loss shall not exceed 3dB over the full environmental range of operation.

Where desired for the intended use, placing the Transmitter into a standby mode shall be permitted.

3.1.1.3 ADS-B Receiver

The UAT receiver shall be capable of supporting the message types and reports required by the application. The receiver antenna feed line loss shall not exceed 3dB over the full environmental range of operation.

3.1.1.4 Report Assembly

The Report Assembly function shall be capable of accepting all message types and generating all reports appropriate to the intended applications.

3.1.1.5 Applications

Applications comprise any use of ADS-B data. Applications shall be developed in accordance with approved standards if standards exist. If approved standards do not exist, the developer shall propose a standard early in the development process to support approval of the operational concept and identify operational limitations.

First time operational approval for the use of installed ADS-B equipment in a given application will be accomplished via the Type Certificate (TC) or Supplemental Type Certificate (STC) approval process. Subsequent installations may be approved via the TC, STC, or field approval process. It is incumbent upon the developer to show that the system meets the requirements of the application. Operating limits of the system shall be included in an approved aircraft/rotorcraft flight manual supplement (AFMS/RFMS).

3.1.2 Aircraft Environment

Equipment shall be installed such that environmental conditions do not exceed the manufacturer's specifications during normal operations.

3.1.3 Aircraft Power Source

The supply voltage and allowable variation shall not exceed the manufacturer's specifications during normal operations. Equipment voltage and frequency tolerance characteristics shall be compatible with an aircraft power source of appropriate category as specified in RTCA/DO-160D.

3.1.3.1 Power Fluctuation

The equipment shall retain memory of variable data through aircraft power transfer, which occurs during normal operation. Typical power transfer involves switching from external power to internal power, either battery or APU generator, or to engine driven

generator(s). The equipment shall not require reinitialization for power transfer (i.e. power loss) for a period up to 0.5 second maximum. Power transfer shall not latch a failure indication. Momentary failure indications, during switching, are allowed.

3.1.4 Accessibility

Controls, indicators, and displays provided for in-flight use shall be readily accessible and/or readable from the pilot's normal seated position. If two pilots are required to operate the aircraft, the controls must be readily accessible from each pilot's seated position. Adequate protection must be provided to prevent inadvertent turnoff of the equipment.

3.1.5 Display Visibility

If there is a control panel display, then appropriate flight crew member(s) must have an unobstructed view of displayed data when in the seated position. The brightness of any display must be adjustable to levels suitable for data interpretation under all cockpit ambient lighting conditions ranging from total darkness to reflected sunlight.

Note: *Visors, glare shields or filters may be an acceptable means of obtaining daylight visibility.*

3.1.6 Indicators

If visual indicators are installed, they shall be visible and readable from the pilot's normal seated position. If two pilots are required to operate the aircraft, indicators shall be visible from each pilot's seated position. The brightness of any indicator must be adjustable to levels suitable under all cockpit ambient lighting conditions ranging from total darkness to reflected sunlight. If an indication is distracting, a means to cancel it should be provided.

3.1.7 Alerts

If appropriate to an application, a means to alert the crew shall be provided. Aural alerts shall provide a mechanism by which they can be prioritized with respect to other aircraft system alerts (e.g. audio inhibit input and output discretes). Aural alerts shall include a means by which they can be silenced.

3.1.8 Failure Protection

Probable failures of the ADS-B equipment must not degrade the normal operation of equipment or systems connected to it. The failure of connected equipment or systems must not degrade normal operation of the ADS-B equipment except for loss of functions directly dependent upon the failed equipment.

3.1.9 Failure Indication

The ADS-B system operational status shall be available to the crew. Failures of the ADS-B transmitter shall be annunciated to the crew. Failures of the ADS-B receiver shall be annunciated to the crew. Though acceptable, dedicated ADS-B transmit and receive failure indicators are not required. Text messages, displayed to the crew until

acknowledged, are acceptable. Systems which combine transmit and receive functions in a common unit may use a single annunciation to indicate a failure.

3.1.10 Interference Effects

The equipment shall not be the source of objectionable conducted or radiated interference nor be adversely affected by conducted or radiated interference from other equipment or systems installed in the aircraft.

***Note:** Electromagnetic compatibility problems noted after installation of this equipment may result from such factors as the design characteristics of previously installed systems or equipment and the physical installation itself. The installing facility is responsible for resolving incompatibilities between the ADS-B equipment and previously installed equipment in the aircraft.*

3.1.11 Mutual Suppression

UAT ADS-B equipment is not required to interface with mutual suppression systems.

3.2 Installed Equipment Performance Requirements

The installed equipment shall meet the requirements of §2.1 and §2.2 in addition to, or as modified by, the requirements stated below.

3.2.1 Antenna Installation

3.2.1.1 General Considerations

Antenna gain and pattern characteristics are major contributors to the system data link performance. The location and number of antennas required for aircraft ADS-B systems is determined by the equipage class. Class A1, A2, and A3 require antenna diversity and must have transmit and receiving capability on both the top and bottom of the aircraft. Class A0 installations do not require antenna diversity. Compliance of the installed antennas with the requirements of §2.1.11 may be demonstrated by analysis. Exceptions may be made for installations on radio-transparent airframes.

If the ADS-B transmitter shares antennas with a Mode-S transponder, the antennas shall comply with the requirements of RTCA Document Number DO-181B.

3.2.1.2 Transmission Lines

Transmission lines between the equipment and the antennas shall have impedance, power handling, and loss characteristics in accordance with the equipment manufacturer's specifications. The VSWR at 978 MHz, as seen through the transmission lines to the antenna(s), shall be within the limits specified by the manufacturer.

The test procedure forces 50 ohms and 1.7:1 VSWR, not consistent with "limits as specified by the manufacturer"

When a transmission line is included as a part of the installation, all minimum installed system performance requirements stated in §2.2, must be met. Test results provided by

the equipment manufacturer may be accepted in lieu of tests performed by the equipment installer.

3.2.1.3 Antenna Polarization

The ADS-B Transmit and Receive antennas shall be predominantly vertically polarized.

3.2.1.4 Antenna Location

Antennas shall be mounted as near as practical to the centerline of the fuselage. Antennas shall be located to minimize obstruction to their fields in the horizontal plane.

Note: *Where possible, it is recommended that the antennas be mounted on the forward part of the fuselage, thereby minimizing blockage due to the vertical stabilizer and engine nacelles.*

3.2.1.5 Minimum Distance from Other Antennas

The spacing between any ADS-B antenna and any DME antenna shall be sufficient to provide a minimum of 20dB of isolation between the two antennas.

Note: *If both antennas are conventional omni-directional matched quarter-wave stubs, 20 dB of isolation is obtained by providing a spacing of at least 51 cm (20 in.) between the centers of the two antennas. If either antenna is other than a conventional stub, the minimum spacing must be determined by measurement.*

3.2.1.6 Minimum Reception Range

Antenna(s) shall be located such that a receiving system reliably receives data from the transmitting aircraft at the minimum range appropriate to the equipage category, as stated in Table 3-1. If a traffic display is installed, reliable data reception is indicated by traffic target acquisition range and smooth movement of traffic targets, without excessive “pop-up,” “drop-out,” or position “jumps.”

Note: *Typical ADS-B antennas have areas of reduced gain, directly above or below the antenna, such that no signal can be received from transmitters in the “cone of silence” or “uncertainty cone.” Reliable data reception from these areas is not required. Approval of operational applications should consider this limitation.*

Table 3-1: Minimum Ranges for Receiving Reliability

Equipage		Required Range (NM)
Class	Type	
A0	Minimum	10
A1	Basic	20
A2	Enhanced	40
A3	Extended	90 (see Note)
A3+	Extended Desired	120 (see Note)

Note: *For each equipage class, the value shown in Table 3-1 corresponds to forward directional coverage. Port and starboard coverage may be one half of this*

value; aft may be one third of this value. (Ref. RTCA/DO-242 Table 3-2(a))
There have been some recent text changes to DO-242A that may need to be applied here as well.

3.2.1.7 Transmit Pattern Gain

The gain of the transmit antenna subsystem **shall** not be less than the gain of a matched quarter-wave stub minus 3 dB, under the following conditions:

- a. Over 90 percent of a coverage volume from 0 to 360 degrees in azimuth and from 5 to 30 degrees above the ground plane,
- b. when installed at center of 1.2 meter (4 feet) diameter (or larger) flat circular ground plane,
- c. Measured at an operating frequency of 978 MHz.

3.2.1.8 Receive Pattern Gain

The gain of the receive antenna subsystem **shall** not be less than the gain of a matched quarter-wave stub minus 3 dB, under the following conditions:

- a. Over 90 percent of a coverage volume from 0 to 360 degrees in azimuth and from 5 to 30 degrees above the ground plane,
- b. when installed at center of 1.2 meter (4 feet) diameter (or larger) flat circular ground plane,
- c. Measured at an operating frequency of 978 MHz.

3.2.1.9 Dynamic Response

The antenna(s) shall be located such that operation of the equipment is not adversely affected by aircraft maneuvering or changes in attitude encountered in normal flight operations.

Note: Class A0 installations are not required to install multiple (e.g. top fuselage and bottom fuselage) antennas.

3.3 Conditions of Test

The following subparagraphs define conditions under which tests, specified in §3.4, shall be conducted.

3.3.1 Safety Precautions

Comply with any specific safety precautions that are recommended by the equipment manufacturer.

3.3.2 Power Input

Unless otherwise specified, all aircraft electrically operated equipment and systems shall be turned ON before conducting interference testing.

3.3.3 Environment

During testing, the equipment shall not be subjected to environmental conditions that exceed those specified by the equipment manufacturer.

3.3.4 Adjustment of Equipment

Circuits of the equipment under test shall be properly aligned and otherwise adjusted in accordance with the manufacturer's recommended practices prior to application of the specified tests.

3.3.5 Warm-up Period

Unless otherwise specified, tests shall be conducted after a warm-up (stabilization) period of not more than fifteen (15) minutes.

3.4 Test Procedures for Installed Equipment Performance

The following test procedures provide one means of determining installed equipment performance. Although specific test procedures are cited, it is recognized that other methods may be preferred by the installing activity. These alternate procedures may be used if they provide at least equivalent information. In such cases, the procedures cited herein should be used as one criterion in evaluating the acceptability of the alternate procedures. The equipment shall be tested to determine compliance with the minimum requirements stated in §2.2. In order to meet this requirement, test results supplied by the equipment manufacturer or other proof of conformity may be accepted in lieu of bench tests performed by the installing activity.

3.4.1 Verification of Antenna Installation (§3.2.1)

No specific test procedure is required to verify compliance with § 3.2.1.

3.4.1.1 Verification of General Considerations (§3.2.1.1)

No specific test procedures are required for §3.2.1.1.

3.4.1.2 Verification of Transmission Lines (§3.2.1.2)

Purpose/Introduction:

The purpose of this procedure is to verify that the VSWR produced by the antenna when terminated in a 50 ohm transmission line does not exceed 1.7:1 at 978 MHz.

Equipment Required:

Appropriate Couplers and Connectors as required. Coaxial Connection of known attenuation (shown in Figure 3-1 and Figure 3-2 as Coax #2). Appropriate Attenuators as required. HP 8562E Network Analyzer (or equivalent capability)

Measurement Procedure:

Step 1: Install Network Analyzer

For ADS-B transmitting installations, disconnect the ADS-B Transmitting device to Antenna connection at the ADS-B Transmitting device unit connector.

For ADS-B receiving installations, disconnect the ADS-B Receiving device to Antenna connection at the ADS-B Receiving device unit connector.

Using appropriate attenuators, connectors, and coaxial cable of known attenuation and impedance, connect the Network Analyzer to the cable end of the Antenna connection (i.e., the connector just removed from the ADS-B Transmitting or Receiving device).

Note: *The use of attenuators is strongly recommended such that the RF front end of the Network Analyzer is not destroyed. If such happens, it is probable that the individual performing the test will not be performing similar tests in the future.*

Step 2: Perform Impedance and VSWR Measurements

Using the Network Analyzer, measure the impedance of the antenna installation at a frequency of 978 MHz.

Verify that the impedance does not exceed 50 ohms.

Using the Network Analyzer, measure the Voltage Standing Wave Ratio (VSWR) of the antenna installation at a frequency of 978 MHz.

Verify that the VSWR does not exceed 1.7:1.

3.4.1.3 Verification of Antenna Polarization (§3.2.1.3)

Appropriate test procedures to verify that the ADS-B Transmitting antenna is vertically polarized are provided in §3.4.1.7, Step [X].

Appropriate test procedures to verify that the ADS-B Receiving antenna is vertically polarized are provided in §3.4.1.8, Step [X].

3.4.1.4 Verification of Antenna Location (§3.2.1.4)

No specific test procedures are required for §3.2.1.4. Requirements for §3.2.1.4 can be verified by measurements of the final installed equipment, or by reference to the manufacturer's installation guide for the equipment.

3.4.1.5 Verification of Minimum Distance from Other Antennas (§3.2.1.5)

No specific test procedures are required for §3.2.1.5. Requirements for §3.2.1.5 can be verified by measurements of the final installed equipment, or by reference to the manufacturer's installation guide for the equipment.

3.4.1.6 Verification of Minimum Reception Range (§3.2.1.6)

Requirements for §3.2.1.6 can be verified during the flight test procedures (see §3.7).

3.4.1.7 Verification of Transmit Pattern Gain (§3.2.1.7)

3.4.1.7.1 Background Material on Gain Performance Verification

Gain performance can be verified using one or a combination of the following procedures:

- a. Full scale antenna range measurements, see §3.4.1.7.1.1.
- b. Scaled model measurements, see §3.4.1.7.1.2.
- c. Theoretical calculations, see §3.4.1.7.1.3.
- d. Distance-area calculations, to ensure that the location of the antenna on the aircraft does not unduly degrade its gain performance, see §3.4.1.7.1.4.

The validation procedure, or combination of procedures, shall be performed using the configuration of the final installed equipment with all appropriate connections and antenna, in order to demonstrate proper operation of the final installation.

3.4.1.7.1.1 Full Scale Anechoic Antenna Range Measurements of Gain

The gain characteristics of the antenna as mounted on the actual airframe may be measured directly in a calibrated anechoic antenna test range using standard controlled procedures for such measurements. Gain characteristics determined in this way require no further validation.

Note: *Anechoic range measurements are generally impractical for determining full antenna gain patterns for large aircraft. However, such techniques may be practical for qualifying certain subregions of the coverage pattern or for validating model measurements or theoretical calculations.*

3.4.1.7.1.2 Scaled Model Measurements of Gain

Aircraft models for antenna measurements are normally 1/10 to 1/40 scale. Scale selection is dependent upon considerations such as availability of equipment, and antenna scaling, with larger models resulting in greater accuracy.

Only the major structural features of the airframe need be constructed. Details such as windows, doors, turbines, etc. are not required. The outside skin should be of conductive material. Typically, the fuselage and engine nacelles are modeled from metal tubing and/or shaped metal screening; wings and stabilizers can be modeled from flat metal plates. Movable control surfaces are not required unless they will have significant effects upon the antenna pattern.

Notes:

1. *In general, obstructions that subtend angles at the antenna of less than a few degrees in elevation or azimuth need not be modeled. However, smaller*

obstructions such as other antennas, that are located within a few wavelengths of the antenna under test, may have to be modeled because they can act as resonant scatterers and could have a significant effect on the radiation pattern.

2. *If the swept area of propeller blades exceeds the limits given in (1) above, the blades can be worst-case modeled by a flat metal disk of radius proportional to blade length. If the radiation pattern using disks for propellers satisfies the success criteria, it can be assumed that the pattern modulation caused by the rotating blades will not significantly degrade the ADS-B system performance.*

3.4.1.7.1.3 Model Tests

Mount the scaled model antenna in the center of a ground plane whose radius is equal in wavelengths to the ground plane used for testing the full scale antenna.

Using a calibrated anechoic antenna test range, confirm that the gain of the scaled antenna (including possible multiple radiating elements, splitting or combining networks, impedance, and mutual coupling effects) is within 2 dB of the full-scale antenna gain, for all azimuth and elevation angles for which the gain of the full-scale antenna is within 6 dB of the peak gain.

Mount the scaled model antenna on the aircraft model at the intended installation location.

Measure the antenna gain for all azimuth angles (for top and bottom antennas).

Confirm that the scaled antenna meets the success criteria of §3.4.1.7.2.

3.4.1.7.1.4 Theoretical Calculations of Antenna Gain

The gain characteristics of the antenna as mounted on the actual airframe may be determined by a combination of radiation pattern calculations, and measurements designed to validate those calculations. When using such techniques to determine the gain of a multi-element antenna, it is necessary to show that the calculations include the inherent characteristics of the antenna elements and their drivers, splitters, or combining networks and any effects due to mutual coupling between those elements.

3.4.1.7.1.4.1 Validation of Theoretical Calculations

If radiation pattern calculations are used to prove the success criteria of §3.4.1.7.2, the manufacturer of the antenna must provide corroborating data demonstrating the success of the calculation technique in predicting the antenna gain on an airframe roughly similar in size and complexity to the airframe under qualification. Such data must be obtained by comparison with selected gain measurements made (a) on a full-size airframe using a calibrated ramp test antenna range (see §3.4.1.7.1.1) or (b) on a scaled model airframe (see §3.4.1.7.1.2).

3.4.1.7.1.5 Distance Area Calculations

The extent to which the antenna installation minimizes obstructions in the horizontal plane and minimizes effects of reflecting objects, may be judged by the distance to such objects and their sizes. If the distances and sizes satisfy the condition given here, then

the antenna installation may be considered validated with regard to antenna gain. The condition is: For target aircraft at zero degree elevation angle and at azimuth bearing between -90 degrees and +90 degrees,

$$\frac{A_1^2}{I^2 D_1^2} + \sum \frac{A_2^2 G_2}{I^2 D_2^2 G'_2} + \sum \frac{A_3 G_3}{4p D_3^2 G'_3} < 0.02$$

where $I = 1.006$ ft. is the free space wavelength at 978 MHz. The first term is applicable only if there is a metallic obstruction between the target and the ADS-B antenna. The distance in feet to the obstruction is denoted D_1 and the area in ft^2 of the obstruction projected in the direction of the ADS-B antenna is denoted A_1 . The second term is a summation over flat metallic reflectors, if any, that are oriented so as to cause a specular reflection between the ADS-B antenna and the target. The distance to the reflector, in feet, is denoted D_2 , the area, in square feet, of the reflector, projected in the direction of the ADS-B antenna is denoted A_2 , the antenna gain in the direction of the reflector is denoted G'_2 and is dimensionless (i.e. gain in dB = $10 \log G'_2$). The third term is a summation over all other metallic objects that may cause reflections between the ADS-B antenna and the target. The parameters D_3 , A_3 , G'_3 , and G_3 have the same meanings as in the second term. In the case of other aircraft antennas in view of the ADS-B antenna, a minimum value for $A = 0.22$ square feet is to be used if the actual area of the antenna is less than 0.22 square feet. What is the source of this value?

3.4.1.7.2 Success Criteria

At an elevation angle of zero degrees relative to the fuselage reference plane, the gain of the forward +/- 45 degree azimuth sector of both the top and bottom antennas shall be no more than one dB below the gain of the antenna when installed on a 4-foot diameter ground plane. The radiation pattern gain, at zero degrees elevation, shall be within 3 dB of the gain of the ground-plane-installed antenna over 90 % of the remainder of its azimuth coverage. The verification procedures of §3.4.1.7.3 shall be performed on final installed equipment with all appropriate connections and antenna in order to demonstrate proper operation of the final installation.

Note: *Antenna system performance tests are specified to accommodate the most stringent envisioned applications. Operational approval of proposed applications must consider installed antenna system performance. Installations that do not fully comply with the above requirements may be approved for particular operations based on the safety implications of the application.*

3.4.1.7.3 Verification Procedure for Transmit Pattern Gain

Purpose/Introduction:

The purpose of this procedure is to verify that the gain of an omni-directional transmit antenna is not less than the gain of a matched quarter-wave stub minus 3 dB over 90 percent of a coverage volume from 0 to 360 degrees in azimuth and from 5 to 30 degrees above the ground plane when installed at center of 1.2 meter (4 feet) diameter (or larger) flat circular ground plane.

This procedure should be performed in the laboratory environment to demonstrate that the ADS-B Transmitting device properly delivers RF ADS-B Messages to the free space medium via the expected installation connections and radiating antenna.

This procedure shall be performed on final installed equipment with all appropriate connections and antenna in order to demonstrate proper operation of the final installation.

Equipment Required:

Provide a method of generating ADS-B Airborne Position Broadcast.

Calibrated quarter-wave stub Sense Antenna of known gain. (See Figure 3-1)

Appropriate Couplers and Connectors as required

Coaxial Connection of known attenuation (shown in Figure 3-1 as Coax #2)

Appropriate Attenuators as required

HP 8753E Spectrum Analyzer (or equivalent capability)

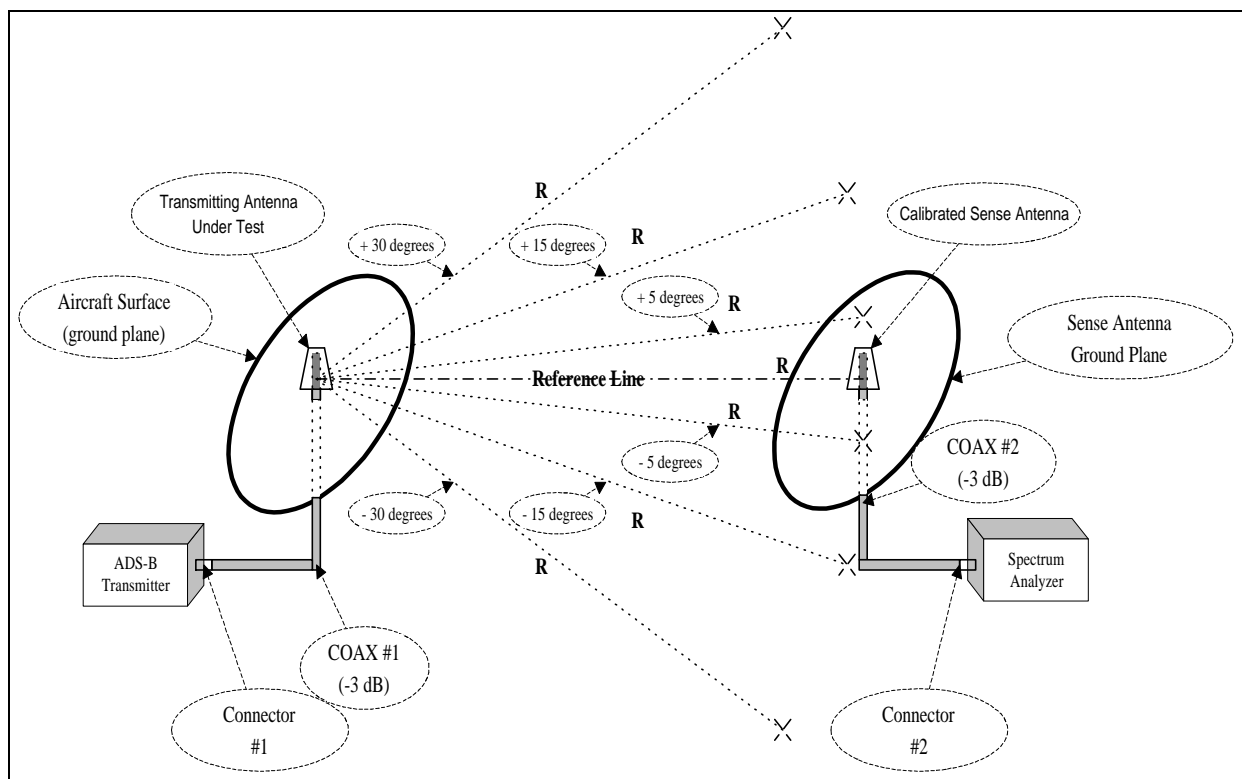


Figure 3-1: Antenna Test Configuration

Measurement Procedure:

Step 1: Understand the Equation

Define:

- P_{out} = Transmitted Power (**in watts**) Measured at the ADS-B Broadcast Message Generator output connector in watts
- $Loss_{TX}$ = **attenuation (in dB)** provided by connection of the ADS-B Broadcast Message Generator to the Transmitting Antenna. This includes the cable (i.e., Coax #1 in Figure 3-1) and connectors
- G_{tx} = gain (**in dB**) of the transmitting antenna
- R = Distance between the transmitting antenna and the receiving antenna in meters

$$\begin{aligned}
\text{Path_Loss} &= \text{attenuation (in -dB) of a 978 MHz signal in free space for distance} = R \\
&= [\lambda/(4\pi R)]^2 = [(300/978)/(4\pi R)]^2 = [(2.44 \times 10^{-2})/R]^2 \\
&= 20*\log(2.44 \times 10^{-2}) - 20*\log(R) \\
&= -32.25 - 20*\log(R)
\end{aligned}$$

$$G_{\text{rx}} = \text{gain (in dB) of the receiving or Calibrated Sense Antenna}$$

$$\text{Loss_RX} = \text{attenuation (in dB) provided by connection of the Calibrated Sense Antenna to the Spectrum Analyzer. This includes the cable (i.e., Coax #2 in Figure 3-1) and connectors and should be calibrated to 3 dB}$$

$$P_{\text{rx_dBw}} = \text{Power (in dBw) received at the Spectrum Analyzer}$$

$$P_{\text{rx_dBm}} = P_{\text{rx_dBw}} - 30 = \text{Power (in dBm) received at the Spectrum Analyzer}$$

Then the expected power of the 978 MHz signal received at the Spectrum Analyzer is given by the following equation.

EQUATION 1:

$$\begin{aligned}
P_{\text{rx_dBw}} &= 10*\log(P_{\text{out}}) - \text{Loss_TX} + G_{\text{tx}} + \text{Path_Loss} + G_{\text{rx}} - \text{Loss_RX} \\
&= 10*\log(P_{\text{out}}) - \text{Loss_TX} + G_{\text{tx}} - 32.25 - 20*\log(R) + G_{\text{rx}} - \text{Loss_RX}
\end{aligned}$$

Specifying a Range of 3 meters (i.e., the distance between the antennas along the reference line shown in Figure 3-1) to be used as the Range in the following procedure provides the following Equation 2.

$$P_{\text{rx_dBw}} = 10*\log(P_{\text{out}}) - \text{Loss_TX} + G_{\text{tx}} - 32.25 - 9.54 + G_{\text{rx}} - \text{Loss_RX}$$

EQUATION 2:

$$P_{\text{rx_dBw}} = 10*\log(P_{\text{out}}) - \text{Loss_TX} + G_{\text{tx}} - 41.79 + G_{\text{rx}} - \text{Loss_RX}$$

Note: *If the measurement distance, R, is different from 3 meters, then Equation 2 must be recomputed for the new R and the recomputation must be based on Equation 1. Equation 1 is based on the fact that there are 1852 meters in one nautical mile. Also, there are 6076.1 feet in one nautical mile. Therefore, for the purpose of these computations, there are 3.28 feet per meter.*

The Effective Radiated Power (ERP) emitted from the Transmitting Antenna is then given by Equation 3 as follows:

EQUATION 3:

$$\text{ERP_dBw} = P_{\text{rx_dBw}} + 41.79 - G_{\text{rx}} + \text{Loss_RX}$$

Note: *Whenever the need to measure radiated RF power is established, the question arises in regards to the permissible level of radiation that can be sustained by personnel making the measurements. This document addresses such concerns in the following paragraph of this note.*

Assume that the maximum Effective Radiated Power from the UAT ADS-B Transmitting Device is 250 W (24.0 dBW) as specified in §2.1.12 of this

document . Then, using portions of equation 2 or 3 from above, the radiated power at 3 meters is given as follows:

$$\begin{aligned} P_{3m_dBW} &= ERP - 41.791 \\ &= 24.0 \text{ dBW} - 41.79 \\ P_{3m_dBW} &= -17.79 \text{ dBW} \end{aligned}$$

then the power at 3 meters in watts is as follows:

$$\begin{aligned} 10 \cdot \log(P_{3m_W}) &= -17.79 \\ P_{3m_W} &= 10^{-1.779} \\ &= 0.0166 \text{ W} \\ &= 16.6 \text{ mW} \end{aligned}$$

This would appear to be a minimum amount of power: however, it does not readily translate into Maximum Permissible Exposure (MPE) limits which are typically used to determine hazard levels.

Consulting FCC OET Bulletin 65, Edition 97-01, August, 1997, "Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields," provides information as provided in the following paragraphs.

Section 2, equation 3, page 19 of the bulletin provides the following equation for the prediction of RF fields:

$$S = \frac{EIRP}{4\pi R^2}$$

where:

$$\begin{aligned} S &= \text{power density (in appropriate units, e.g. mW/cm}^2\text{)} \\ EIRP &= \text{equivalent (or effective) isotropically radiated power (in appropriate units, e.g. mW)} \\ R &= \text{distance to the center of radiation of the antenna (appropriate units, e.g., cm)} \end{aligned}$$

Applying this equation at 3 meters to the maximum radiated power (e.g., 250 W) allowed for UAT ADS-B Transmitting functions provides the following results:

$$\begin{aligned} S &= \frac{(250 \text{ W})(1000 \text{ mW/W})}{4\pi(300 \text{ cm})^2} \\ &= 0.221 \text{ mW/cm}^2 \end{aligned}$$

Appendix A, Table 1(A) of the bulleting then provides MPE limits for Occupational/Controlled Exposure as follows:

$$\begin{aligned} \text{Frequency Range (MHz)} &= 300 - 1500 \\ \text{Electric Field Strength (E) (V/m)} &= \text{Not Applicable} \\ \text{Magnetic Field Strength (H) (A/M)} &= \text{Not Applicable} \\ \text{Power Density (S) (mW/cm}^2\text{)} &= f/300 \\ \text{Averaging Time, S (minutes)} &= 6 \end{aligned}$$

Therefore, the MPE exposure for an average of 6 minutes at 978 MHz is:

$$S_{MPE_978} = (978)/300 = 3.26. \text{ mW/cm}^2$$

Note that this limit value is over 14 times greater than the power density at 3 meters computed above as 0.221 mW/cm^2 .

Next, the time of exposure must be considered. Page 11 of the bulletin addresses this concern with the equation:

$$S_{exp} t_{exp} = S_{limit} t_{avg}$$

where:

S_{exp} = power density of exposure (mW/cm^2)

S_{limit} = appropriate power density MPE limit (mW/cm^2)

t_{exp} = allowable time of exposure for S_{exp}

t_{avg} = appropriate MPE averaging time

Taking into the consideration that the ADS-B Transmitting Device will never exceed a transmitting duty cycle of .05% (one message per second, which does not exceed 500 microseconds duration), the allowable time of exposure is computed from the above equation as follows:

$$(0.221 \text{ mW/cm}^2) * X * (0.0005) = (978/300 \text{ mW/cm}^2) (6 \text{ minutes})$$

$$X = \frac{(978/300 \text{ mW/cm}^2) (6 \text{ minutes})}{(0.221 \text{ mW/cm}^2) (0.0005)}$$

$$X = 177 \times 10^3 \text{ minutes}$$

or

$$X = 2,950 \text{ hours}$$

These calculations have demonstrated that the expected power density of the ADS-B transmitting function at 3 meters is well within the allowable MPE.

Step 2: Measure the Output Power of the ADS-B Transmitting function or device

On the Aircraft (or other applicable installation), disconnect the ADS-B Transmitting device to Antenna connection at the ADS-B Transmitting device unit connector.

Using appropriate attenuators, connectors, and coaxial cable of known attenuation of 3 dB and impedance of 50 ohms, connect the Spectrum Analyzer to the ADS-B Transmitting device.

Note: The use of attenuators is strongly recommended such that the RF receiver front end of the Spectrum Analyzer is not destroyed.

Configure the ADS-B Transmitting function to transmit ADS-B Surface Position Messages.

Using the Spectrum Analyzer set at a center frequency of 978 MHz, capture the power envelope of ADS-B message transmission.

Verify that the frequency is at 978 MHz +/- 20 PPM.

For Class A0 and A1L equipment, verify that the output power is at least 7 watts (i.e., +38.5 dBm). Log the measurement as P_{out}.

For Class A1H and A2 equipment, verify that the output power is at least 15.8 watts (i.e., +42.0 dBm). Log the measurement as P_{out}.

For Class A3 equipment, verify that the output power is at least 100 watts (i.e., +50.0 dBm). Log the measurement as P_{out}.

Step 3: Re-connect Aircraft Installation

Disconnect the Spectrum Analyzer from the ADS-B transmitting device.

Restore the normal aircraft (or other) installation connection of the ADS-B transmitting antenna to the ADS-B transmitting device.

Step 4: Establish Measurement Reference #1

Refer to Figure 3-1.

Using an appropriate strong nylon string or similar, secure the string to the Calibrated Sensing Antenna and to the Aircraft Antenna under test such that the two antenna are exactly 3 meters apart along the reference line shown in Figure 3-1. Make sure that the two antennas are at the same height from a relatively level surface. Note this position of the Calibrated Sensing Antenna as the **baseline** position.

Then, move the Calibrated Sensing Antenna to a point that is 5 degrees above the baseline position while maintaining the Calibrated Sensing Antenna perpendicular to the string with the string being tight but not stretched. Note this position as the **#1 Reference Position**.

Configure the ADS-B Transmitting function to transmit ADS-B Surface Position Messages.

Using the Spectrum Analyzer set at a center frequency of 978 MHz, capture the power envelope of an ADS-B message transmission. Then measure and note the power.

For Class A0 and A1L equipment, verify that the output power is at least 7 watts (i.e., +38.5 dBm). Log the measurement as ERP_{dBm}.

For Class A1H and A2 equipment, verify that the output power is at least 15.8 watts (i.e., +42.0 dBm). Log the measurement as ERP_{dBm}.

For Class A3 equipment, verify that the output power is at least 100 watts (i.e., +50.0 dBm). Log the measurement as ERP_{dBm}.

Step 5: Circular Measurements

Keeping the Calibrated Sensing Antenna at 5 degrees above the baseline position as specified in Step 4, move the Calibrated Sensing Antenna in the horizontal plane in approximately 45 degree steps such that new positions are

established at approximately 45, 90, 135, 180, 225, 270, and 315 degrees relative to **#1 Reference Position**.

At each new position, repeat the power measurement taken in Step 4 and log the results in dBw.

Verify that the maximum deviation between any two measurements taken in Step 4 and this Step does not exceed 1 dBw.

Step 6: Establish new reference #2

Repeat Step 4 with the Calibrated Sensing Antenna moved to a position that is 15 degrees above the **baseline** position. Note this position as the **#2 Reference Position**.

Repeat the power measurement made in Step 4.

Verify that the maximum difference between the measurement and that taken in Step 4 does not exceed 1 dBw.

Repeat Step 5 about the **#2 Reference Position** while maintaining the Calibrated Sensing Antenna at 15 degrees above the baseline position.

Verify that the maximum deviation between any two measurements taken in this Step does not exceed 1 dBw.

Step 7: Establish new reference #3

Repeat Step 4 with the Calibrated Sensing Antenna moved to a position that is 30 degrees above the baseline position. Note this position as the **#3 Reference Position**.

Repeat the power measurement made in Step 4.

Verify that the maximum difference between the measurement and that taken in Step 4 does not exceed 1 dBw.

Repeat Step 5 about the **#3 Reference Position** while maintaining the Calibrated Sensing Antenna at 30 degrees above the baseline position.

Verify that the maximum deviation between any two measurements taken in this Step does not exceed 1 dBw.

Step 8: Establish new reference #4

Repeat Step 4 with the Calibrated Sensing Antenna moved to a position that is 5 degrees below the baseline position. Note this position as the **#4 Reference Position**.

Repeat the power measurement made in Step 4.

Verify that the maximum difference between the measurement and that taken in Step 4 does not exceed 1 dBw.

Repeat Step 5 about the #4 Reference Position while maintaining the Calibrated Sensing Antenna at 5 degrees below the baseline position.

Verify that the maximum deviation between any two measurements taken in this Step does not exceed 1 dBw.

Step 9: Establish new reference #5

Repeat Step 4 with the Calibrated Sensing Antenna moved to a position that is 15 degrees below the baseline position. Note this position as the **#5 Reference Position**.

Repeat the power measurement made in Step 4.

Verify that the maximum difference between the measurement and that taken in Step 4 does not exceed 1 dBw.

Repeat Step 5 about the **#5 Reference** Position while maintaining the Calibrated Sensing Antenna at 15 degrees below the baseline position.

Verify that the maximum deviation between any two measurements taken in this Step does not exceed 1 dBw.

Step 10: Establish new reference #6

Repeat Step 4 with the Calibrated Sensing Antenna moved to a position that is 30 degrees below the baseline position. Note this position as the **#6 Reference Position**.

Repeat the power measurement made in Step 4.

Verify that the maximum difference between the measurement and that taken in Step 4 does not exceed 1 dBw.

Repeat Step 5 about the **#6 Reference** Position while maintaining the Calibrated Sensing Antenna at 30 degrees below the baseline position.

Verify that the maximum deviation between any two measurements taken in this Step does not exceed 1 dBw.

3.4.1.8 Verification of Receive Pattern Gain (§3.2.1.8)

The background material of §3.4.1.7.1 applies equally to verification of Receive Pattern gain.

Note: *If the installed equipment uses the same antenna for both transmission and reception of ADS-B messages, the procedure of §3.4.1.8 is not required. Receive antenna gain pattern is symmetric with the transmitted gain performance.*

Purpose/Introduction:

The purpose of this procedure is to verify that the gain of an omni-directional antenna should is not less than the gain of a matched quarter-wave stub minus one dB over 90% of a coverage volume from 0 to 360 degrees in azimuth and -15 to +20 degrees in elevation when installed at the center of a 1.2 m (4 ft.) diameter (or larger) circular ground plane that can be either flat or cylindrical.

This procedure shall be performed on final installed equipment with all appropriate connections and antenna in order to demonstrate proper operation of the final installation.

Equipment Required:

Provide the same equipment capability as that provided in §3.4.1.7.3.

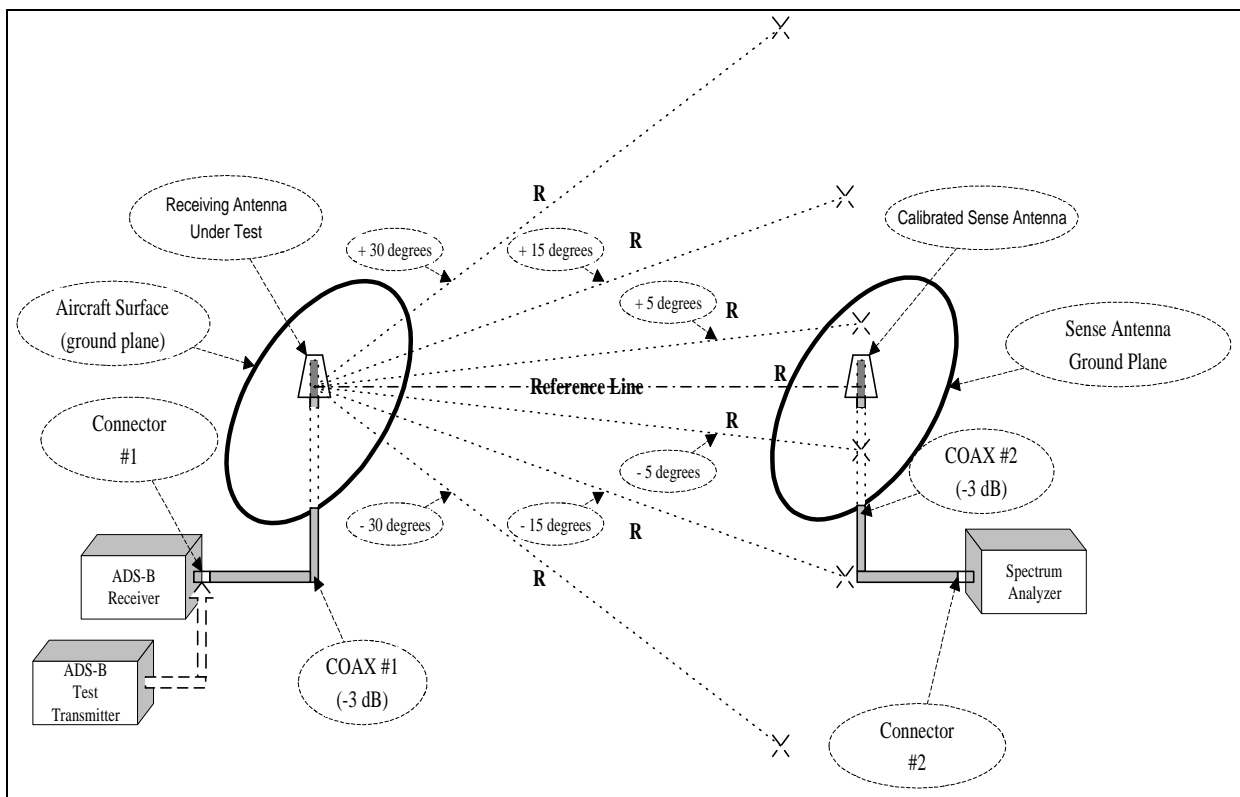


Figure 3-2: Antenna Test Configuration

Measurement Procedure:

Note: Figure 3-2, above, is exactly the same as Figure 3-1 provided in §3.4.1.7.3 with the exception that:

- a. The ADS-B Transmitter in Figure 3-1 has been replaced with an ADS-B Receiver and an ADS-B Test Transmitter that is to be patched in for this test procedure.
- b. The Transmitting Antenna under Test in Figure 3-1 has been replaced with a Receiving Antenna under Test.

Step 1: Install ADS-B Transmission Capability

On the Aircraft (or other applicable installation), disconnect the ADS-B Receiving Device to Antenna connection at the ADS-B Receiving device unit connector.

For Class A0 and A1L Receiver installations, install a ADS-B Test Transmitting device having a minimum RF power of least 7 watts (i.e., +38.5 dBm) *plus* 3 dB. If additional cabling or connectors are required to make the connection, then the added attenuation must be accounted for when applying the equations given in §3.4.1.7.3 in this procedure.

For Class A1H and A2 Receiver installations, install a ADS-B Test Transmitting device having a minimum RF power of least 15.8 watts (i.e., +42.0 dBm) *plus* 3 dB. If additional cabling or connectors are required to make the connection, then the added attenuation must be accounted for when applying the equations given in §3.4.1.7.3 in this procedure.

For Class A3 Receiver installations, install a ADS-B Test Transmitting device having a minimum RF power of least 100 watts (i.e., +50.0 dBm) *plus* 3 dB. If additional cabling or connectors are required to make the connection, then the added attenuation must be accounted for when applying the equations given in §3.4.1.7.3 in this procedure.

At this point, the ADS-B Receiving device of the ADS-B Receiving installation has been replaced with an appropriate RF source such that the radiated pattern of the receiving antenna installation can be verified. The premise here is that if the radiated pattern is good, then so is the reception pattern.

Step 2: Perform Radiated Pattern Tests

Using the equations given in §3.4.1.7.3, with appropriate modifications if necessary, repeat steps 2 through 10 of §3.4.1.7.3.

Step 3: Restore Original Installation

Disconnect and remove the ADS-B Test Transmitter and restore the original installation of the ADS-B Receiving device.

3.4.1.9 Verification of Dynamic Response (§3.2.1.9)

No specific test procedures are required for §3.2.1.9. The Dynamic Response requirements of §3.2.1.9 are best verified by analysis of the antenna mechanical properties and the installation locations.

3.5 Flight Environment Data Sources

Aircraft systems and/or sensors, which supply flight environment data to the ADS-B system, shall be selected to meet the accuracy, range, and resolution requirements appropriate to the equipage category. (Accuracy, range, and resolution may be shown to be adequate by analysis.)

3.5.1 Navigation Integrity Category (NIC)

The system shall report (and adjust, if necessary) NIC values appropriate to the navigation source (including its operational mode), which supplies data to the ADS-B system. NIC value varies with navigation source selection and the selected sensor's current performance. If the aircraft has multiple navigation systems, NIC can vary with system selection and the mode of operation (e.g. Inertial Navigation with DME or GPS augmentation). The reported NIC value must vary to track navigation integrity (NIC) as it increases or decreases, corresponding to navigation system integrity

3.5.2 Altitude

Barometric Pressure Altitude relative to a standard pressure of 1013.25 millibars (29.92 in.Hg.) shall be supplied to the ADS-B system. Altitude data, which is correctable for local barometric pressure, shall not be supplied to the ADS-B system. The ADS-B system and the ATC transponder (if installed) shall derive Pressure Altitude from the same sensor (e.g. air data computer or encoding altimeter).

3.5.3 Surface / Air (Vertical) Status

Aircraft systems or sensors providing vertical status to the ADS-B system shall be implemented such that they provide a reliable indication that the aircraft is on the ground or airborne. When considering likely failure modes, the system should fail to the "air" mode where possible (e.g. air/ground relay should relax to the "air" mode).

3.6 Aircraft / Vehicle Data

ADS-B messages contain information describing the aircraft or vehicle, which is transmitting. It is a responsibility of the installer to insure that the vehicle information provided to the ADS-B system is correct.

3.6.1 Fixed Data

Data that do not change during operation are selected or loaded at installation (e.g. ADS-B Emitter Category, ICAO address). Fixed data shall accurately represent the individual airplane/vehicle characteristics or registration information. If ADS-B and a Mode-S transponder are installed, both shall use the same ICAO address (whenever both are operating).

3.6.2 Variable Data

Controls used by the pilot/crew for data entry (e.g. flight number, call sign, emergency status) shall correctly perform their intended functions.

Note: Where regulations permit variation of the 24 bit Mode-S and /or ADS-B address, ADS-B and a Mode-S transponder shall use the same ICAO address (whenever both are operating).

3.6.3 ON-Condition Sensors

Aircraft systems or sensors used to trigger on-condition messages shall be selected and implemented such that they provide a reliable indication of the specific condition(s) to be reported.

3.7 Flight Test Procedures

This guidance material offers examples of flight test procedures for demonstration of performance of selected functions.

Flight testing of installed systems may be desirable to confirm or supplement bench and ground tests of installed performance.

Flight tests are not necessary to evaluate functions that encode, communicate, and decode messages, assemble reports, or generate displays, except for the radio frequency functions associated with transmission and reception of ADS-B messages.

3.7.1 Displayed Data Reliability

Determine that normal conditions of flight do not significantly affect the readability of displayed data.

3.7.2 Interference Effects

For those aircraft systems and equipment that can only be tested in flight, determine that no operationally significant conducted or radiated interference exists. Evaluate all reasonable combinations of control settings and operational modes.

Note: *Electromagnetic interference flight tests are often conducted on all electronic systems in one test series, using procedures established by the aircraft manufacturer. If such tests included the ADS-B equipment, no further tests are required. (e.g., ADS-B functionality added to an existing transponder and/or TCAS installation)*

3.7.3 ADS-B Performance Testing

The ADS-B flight test is designed to verify that the installed ADS-B system is capable of transmitting and/or receiving ADS-B messages from other aircraft. The following suggested procedures are typical flight test plans that could be followed in a region of low air traffic density: but any other test that supplies equivalent data would be acceptable.

ADS-B system testing requires verification of transmission and reception of ADS-B messages at the minimum range for the equipage class. If testing an aircraft installation (“Subject”) which broadcasts only, the receiving equipment (“Target”) must provide a means to display message information, received from the Subject, to the operator.

Shorter range (10-20 NM) operational requirements may be demonstrated using a ground based Target system. Longer range operation might require an airborne Target system. Typically the airborne Target aircraft will fly a holding pattern at a designated fix and within 3000 feet of the Subject aircraft altitude.

Fly the Subject aircraft straight and level at the minimum operational range and verify that data from the Subject are received reliably by the Target system. If the Subject system has receive capability, verify that the Subject system reliably reports information about the Target. (e.g. displays Target at appropriate range and altitude with correct identification)

Note: *It is not intended that reception of individual ADS-B messages be verified.*

Fly the Subject aircraft in a figure 8 pattern, at the minimum operational range, at bank angles consistent with normal operations, at a constant altitude, and verify that transmitted data are received reliably by the Target system. If the Subject system has receive capability, verify that the Subject system reliably reports information about the Target during maneuvering. (e.g. displays Target at appropriate range and altitude with correct identification)